MISCELLANEOUS EQUIPMENT IN COMMERCIAL BUILDINGS: THE INVENTORY, UTILIZATION, AND CONSUMPTION BY EQUIPMENT TYPE

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The nature of the miscellaneous equipment (devices other than permanently installed lighting and those used for space conditioning) in commercial buildings is diverse, comprising a wide variety of devices that are subject to varied patterns of use. This portion of the commercial load is frequently underestimated, and widely hypothesized to be growing. These properties make it a particularly difficult load to characterize for purposes of demand-side management.

In the End-Use Load and Consumer Assessment Program (ELCAP), over 100 commercial sites in the Pacific Northwest have been metered at the end-use level for several years. Detailed inspections of the equipment in them have also been conducted. This paper describes how the ELCAP data have been used to estimate three fundamental properties of the various types of equipment in several classes of commercial buildings: (1) the installed capacity per unit floor area, (2) utilization of the equipment relative to the installed capacity, and (3) the resulting energy consumption by building type and for the Pacific Northwest commercial sector as a whole. Applications for the results include assessment of conservation potential, prediction of equipment loads from survey data, estimating equipment loads for energy audits, targeting of conservation technology development, and disaggregating building total or mixed end-use data.

INTRODUCTION

A wide variety of equipment with highly varying patterns of usage is found in commercial buildings. In this analysis, the term *equipment* is defined to mean all energy-consuming devices in commercial buildings, except for permanently installed lighting and devices used for heating, ventilating, and air conditioning. Equipment thus includes devices such as typewriters, personal and mainframe computers, copying machines, refrigerators, ovens, grills, task lights, elevators, water heaters, dishwashers, and power tools. Previous studies conducted to characterize equipment in the commercial sector have been limited by a lack of both equipment inventory data for a large building population and actual metered loads (Alereza and Breen 1984) (Norford et al. 1988).

Other work using metered data has shown that equipment loads are consistently overestimated by about 60% in energy audits of commercial buildings (Cambridge Systematics 1988; Pratt 1989). Whether this is due to a lack of detailed surveys of equipment in the buildings and/or a misestimation of their utilization is not clear. Commercial sector equipment loads have been widely hypothesized to be rapidly growing, partly as a result of the introduction of office automation equipment. Clearly, there is a need for greater knowledge of these loads.

This study focuses primarily on equipment that consumes electricity rather than fossil fuels, using survey data of the equipment inventory and metered end-use data collected for 140 commercial buildings in the Pacific Northwest as part of the End-use Load and Consumer Assessment Program (ELCAP). (The general end-use load and load shape results for the ELCAP commercial sector have been published elsewhere [Taylor and Pratt 1989]). This paper describes the quantity of various categories of equipment found in each commercial building type and estimates their usage as a function of the installed capacity. From this basic information, estimates of loads for each equipment category in eleven building types are developed. When the load estimates are multiplied by regional estimates of commercial floor space, a view of commercial sector equipment loads is provided. The results provide a baseline for more accurate estimates of future load growth in commercial equipment loads and the energy conservation potential in specific types of equipment and technologies.

SUMMARY OF THE EQUIPMENT POPULATION

The ELCAP connected load inventory is a catalogue of all equipment in each building, indicating the equipment type, nameplate capacity rating, location, type of fuel used (gas equipment is included in the inventory), and the end-use on which its consumption is metered. Each piece of equipment in buildings is required to have a label indicating its nominal "nameplate" capacity rating, in watts (W) or British thermal units (Btu). The nameplate capacity is a rough indication of the power drawn when the device is operating. As the nameplate ratings are for use in determining required wire sizes, they are actually an upper limit for the normally required power level. In the protocol for the ELCAP connected load inventory, nameplate capacity ratings were recorded for all equipment with ratings over 1 kilowatt (kW). When a number of similar but small devices were present in a building, they were inventoried if their combined ratings exceeded this limit, although the surveyors tended to also record many individual devices with capacity ratings less than 1 kW.

Equipment Categories

The equipment categories used are listed in Table 1. Although the connected load inventory provides much greater detail about the types of equipment in each building, these broad categories were selected to summarize it. Several of the categories reflect known or suspected differences in typical usage patterns. In particular, the food preparation, vertical transport, and miscellaneous equipment each were separated into two classes--continuous use and intermittent use--based on the likely possibility that their usage patterns are different. Similarly, refrigeration equipment was subdivided into two classes--unitary and central. Unitary equipment is a stand-alone package; a residential-style refrigerator, a water cooler, and a restaurant salad case are examples. Central refrigeration equipment is larger, typically assembled from separate components, and often driven from a central compressor system that may service multiple refrigeration or freezer cases.

Types of equipment common to both personal and large mainframe or network computer systems were not differentiated by the equipment inventory, so they are distinguished here on the basis of their nameplate capacities. Task lighting equipment was defined as the lights metered on the Mixed General and Receptacles end uses in the ELCAP database (end uses are capitalized in this paper to distinguish them from equipment categories). However, because of the complexity of the electric circuitry in many commercial buildings, the Mixed General end use category does contain some fixed overhead (nontask) lights, particularly for lobbies and bathrooms. (This is the principal reason the Mixed General end use was defined in the ELCAP metering protocol). Thus, compared to the traditional definition of task lighting, the capacities here are likely to be overestimated.

Capacity Densities by Building Type

In each building, two kinds of information about the equipment in each category were summarized: the number of individual devices, and the total nameplate capacity ratings in each building. These were divided by the building floor area to produce equipment device density (devices/square foot) and capacity density (kilowatts/square foot), and then averaged across buildings within building types to produce an equipment population summary. Thus,

Table 1. Commercial Building Equipment Categories

Equipment Category	Definition of Category
Office Equipment	Typewriters, copiers, cash registers
Food Preparation-Continuous	Grills, ovens, fryers, broilers, steamers, hot drink machines, warmers
Food Preparation-Intermittent	Slicing, grinding, mixing, and all other non-cooking equipment
Laboratory	Medical, photography, electronic, testing equipment
Hot Water	All water heating equipment
Material Handling	Conveyors, wrappers, hoists, and compactors
Refrigeration-Unitary	Domestic-type refrigerators and freezers, ice machines, water coolers, other small coolers
Refrigeration-Central	All large cooling and freezing equipment or those powered by separate compressors
Sanitation	Washers, disposals, dryers, cleaning equipment
Vertical Transport-Continuous	Escalators
Vertical Transport-Intermit.	Elevators, dumb waiters, and window washers
Shop	Tools and electronic testing equipment
Miscellaneous-Continuous	Sign motors, time clocks, vending machines, phone equipment, sprinklers
Miscellaneous-Intermittent	Scoreboards, fire alarms, intercoms, audio/visual equipment, door operators
Personal Computer Equipment	Small terminals, personal computers, disk drives, central processors, and printers[1]
Large Computer Equipment	Larger multi-user or network terminals, disk drives, central processors, and printers[1]
Task Lighting	Lights metered on mixed use circuits (thus not strictly task lighting, see text)

[1] *Personal and large computer equipment differentiated by capacity ratings, not by inspection. See text.*

each building is given equal weight in determining the average amount of equipment in its building type. This prevents the averages from being dominated by the equipment in a few large buildings. Buildings without any equipment of a given category were assigned a capacity density of zero for that category, producing a true sample average. The resulting capacity densities are shown in Table 2.

The building types in Table 2 correspond to those used by Bonneville for its regional planning. The office and retail building types are split into two sizes based on floor area, with a cutoff of 30,000 ft^2. The number of buildings within each building type used to develop the summaries, and the number of individual devices in the survey, are also shown in Table 2. Five of the major building types--office, retail, grocery, restaurant, and warehouse--have relatively large sample sizes. Four additional building types--hotel, school, university, and other--are represented by much smaller sample sizes.

Using large offices as an example, the total capacity density of computer equipment is nearly 0.9 W/ft^2 of floor area. Large computers comprise about two thirds of this capacity, with the remainder being personal computer equipment. Other types of general office equipment are present in densities about 0.7 Watts/ft^2. The equipment types with largest electric capacity are laboratory (1.6 W/ft^2), followed by intermittent vertical transportation equipment (elevators) at 1.1 W/ft^2. Both categories of food preparation equipment represent a surprisingly large 0.7 W/ft^2. Data on device densities, indicating both the quantity and average size of the equipment involved, are not reported here (but will be included in a report soon to be published by the Bonneville Power Administration).

Table 2. Commercial Building Equipment Capacity Densities (1985/86)

Equipment Category	Small Office	Large Office	Small Retail	Large Retail	Res-taurant	Grocery	Ware-house	Grade School	Univer-sity	Other	Hotel/ Motel
Electric Equipment (W/ft^2)											
Office (General)	0.73	0.66	0.52	0.04	0.16	0.07	0.22	0.08	0.59	0.08	0.03
Personal Computer	0.27	0.64	0.12	0.00	0.08	0.03	0.09	0.01	0.32	0.00	0.05
Large Computer	0.18	0.23	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Task Lighting	0.10	0.05	0.00	0.31	0.07	0.04	0.01	0.00	0.00	0.00	1.29
Laboratory	0.09	1.62	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00
Vert.Trans-Contin.	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vert.Trans-Intrmt.	0.22	1.08	0.00	0.21	0.13	0.08	0.04	0.00	0.16	0.00	0.00
Shop	0.12	0.15	1.18	1.76	0.00	0.18	1.24	0.05	0.68	11.75	0.03
Misc.-Continuous	0.05	0.13	0.02	0.00	0.18	0.05	0.02	0.00	0.04	0.02	0.03
Misc.-Intermittent	0.17	0.77	0.91	0.09	0.15	0.14	0.02	0.42	0.63	0.67	2.05
Material Handling	0.18	0.13	0.33	0.14	0.27	0.32	0.33	0.00	0.43	3.23	0.05
Food Prep.-Contin.	2.06	0.63	0.56	0.23	9.60	2.41	0.30	1.21	0.71	0.99	2.10
Food Prep.-Intrmt.	0.18	0.08	0.12	0.01	1.89	0.64	0.02	0.09	0.01	0.13	0.34
Refrig.-Unitary	0.37	0.20	0.45	0.04	2.43	2.01	0.07	0.12	0.10	0.15	0.31
Refrig.-Central	0.04	0.05	0.12	0.02	3.56	7.24	0.00	0.05	0.00	0.00	0.01
Sanitation	0.20	0.28	0.06	0.05	0.62	0.06	0.05	0.22	0.02	5.20	1.05
Hot Water	0.96	0.26	1.99	0.26	2.56	1.09	0.87	3.28	0.74	0.85	3.14
Fuel Equipment Capacity Densities (W/ft^2 - Input)											
Shop	0.00	0.00	0.32	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Misc.-Intermittent	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Food Prep.-Contin.	0.31	0.21	0.41	0.00	10.76	0.11	0.10	0.00	0.00	2.69	0.47
Sanitation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	32.95	3.99
Hot Water	0.35	2.75	0.45	0.27	4.57	0.24	0.04	4.02	0.51	20.85	4.42
# of Buildings =	19	7	19	8	15	13	19	4	5	2	8
# of Devices Inventoried =	1482	3653	592	885	2206	1016	740	594	198	770	1134

Devices that use fuels other than electricity are also important for many analyses, particularly those involving internal heat generated by the equipment and how it affects heating and cooling loads. In such cases, the fuel used to generate the heat is largely irrelevant. Other regions may have different fuel penetrations, and so these data help generalize the capacity densities. Also, the quantities and types of non-electric equipment in the buildings may be useful in identifying fuel-switching opportunities. The total capacities of fuel powered equipment are also included in Table 2. For example, including gas equipment capacities in large offices, hot water and food preparation equipment capacity densities increase to about 3.0 and 0.9 W/ft^2, respectively. This indicates, for example, that hot water equipment in large offices in the Pacific Northwest is primarily powered by fossil fuels.

Notes Regarding Application of the Results

In using these results for future analyses, some limitations as to their source and derivation need to be recognized. The ELCAP commercial sample is only partially random, principally located in Seattle, and lacks the very large office buildings typical of urban centers. As can be seen in Table 2, the sample sizes for some building types are limited; some users may wish to ignore the distinction between large and small buildings, for example. The connected load inventory data were supplemented by using 33 additional ELCAP sites from a nonrandom sample of audited buildings. It is not currently possible to estimate bias in the quantity or usage of the equipment in the ELCAP sample with respect to that in the national commercial building population. (Taylor and Pratt [1990] discuss the ELCAP commercial samples).

The connected load inventory was conducted when the metering equipment was installed (principally 1985 and 1986), and although subsequent updates of the inventory are planned, none had been conducted at the time of this analysis. In some cases, the surveyors could not read the labels, due to missing (principally due to age) or inaccessible labels, so it was necessary to "fill" 18% of the nameplate ratings with the average nameplate ratings for similar devices in the other buildings. As described above, the task lighting category necessarily includes some overhead (though specialized) lighting, and the differentiation of personal and large computer equipment is inexact. Despite these limitations, the ELCAP equipment inventory is the largest and most detailed set of such information available at the present time.

EQUIPMENT UTILIZATION

A high capacity density may not indicate high annual electricity consumption if the equipment is only rarely used. For example, food preparation equipment in small offices tends to have large capacity densities (due to the common presence of residential kitchen appliances in lunch rooms) but may be used only a few minutes a day. The second set of basic information provided by this analysis is the utilization of the equipment, defined here as the ratio of the electricity consumed to the nameplate capacity rating of a device. It is convenient to think of the utilization as the fraction of time the equipment is in use. For many types of equipment that operate steadily at or near their rated power, this is approximately true. However, this is often misleading, since many types of equipment consume power at levels well below their nameplate rating in various modes of operation (an idle photocopier compared to one actively copying, for example). Consequently, the utilization factor is only *proportional* to the time of use, and actually represents the product of the fractional time of use and a load factor:

$$\text{Utilization factor} = \text{Fractional time of use} * \text{Load Factor} \quad (1)$$

$$\text{Utiliz factor} = \frac{\text{Hours "on"/yr}}{\text{8760 hr/yr}} * \frac{\text{Avg power (kW) when "on"}}{\text{Nameplate label rating power (kW)}} \quad (2)$$

For example, a personal computer that is "on" an average of 50 hours a week has a fractional time of use of 50 / (7 * 24) = 30%. If its load factor is measured or known to be 50%, then its utilization factor is 30% * 50% = 15%.

While fractional time of use is easier than utilization to interpret in behavioral terms, it is rare that single devices are metered on a data logger channel in the ELCAP commercial buildings. Load factors cannot be readily determined from the metered data, but it is possible to estimate utilization factors by re-arranging Equation (2) as the ratio of consumption to capacity

$$\text{Utiliz Factor} = \frac{\text{Consumption (kWh/yr) / 8760 (hours/yr)}}{\text{Nameplate label rating power (kw)}} \quad (3)$$

Equation (3) points out that utilization factors are convenient for use in conjunction with surveys of equipment capacities in buildings, since an estimate of the consumption can then be computed. Continuing the previous example, if the nameplate rating of the computer is 240 W (0.24 kW), then its annual consumption is 15% * 0.240 kW * 8760 hr/yr = 315 kWh/yr.

Utilization Estimation Methodology

When a single equipment category is uniformly metered on an end use across buildings, the utilization can be estimated from a regression across buildings of the form

$$Y = A\,X \quad (4)$$

where Y is a vector of end-use consumption for a set of buildings and X is a vector of the nameplate capacity data for the equipment metered on the end use. Both X and Y are normalized by floor area to prevent the larger buildings from dominating the slope of the regression. As Equation (4) has no intercept term, and so must pass through the origin, buildings with large capacities and loads would apply more "leverage" in determining the slope (A) of the regression. The coefficient (A) can be interpreted as an "average" utilization factor for the buildings that minimizes the sum of the squared deviations from the linear model.

In practice, the use of ELCAP metered end-use and connected load inventory data to estimate utilization factors is not as straightforward as suggested by Equation (4), for several reasons. These can be summarized as being related to (1) the ELCAP metering protocol, (2) statistical issues, and (3) selection of the best utilization factor for an equipment category when multiple estimates are obtained. These issues are briefly discussed below.

First, the defined equipment categories are finer in resolution than the protocol defining ELCAP end uses, so loads from more than one category often appear on a single metered end use. Second, equipment from a single category are metered on more than one end use. Usually this is because the more general Receptacles or Mixed General end uses are applied when loads are estimated to be less than 90% "pure" (instead of the more specific end uses used whenever possible). An example is computer equipment, which may be metered on either the Receptacles or Data Processing end uses, depending on the centralized or diffuse location of the equipment in the buildings and the number of data logger channels available. By the same rule, small amounts of equipment from another category (less than 10% of the load) are allowed on the specific end uses as well.

To deal with these protocol-related issues, a multiple linear regression is used of the form

$$Y_e = A_{1e}X_{1e} + A_{2e}X_{2e} + \dots A_{ie}X_{ie} \dots + A_{Ne}X_{Ne} \qquad (5)$$

where X_{ie} is a vector of the capacity densities for the ith category of the N equipment categories metered on end use e and A_{ie} is the corresponding utilization factor. Separate regressions in the form of Equation (5) are written for each of the end uses within each building type in the ELCAP protocol. (This is how multiple utilization estimates are obtained for a single equipment category.) In the example cited above, a utilization factor for computers in offices could be estimated from both the Receptacles and Data Processing regressions.

A number of statistical issues arise in working with the regressions of Equation (5) for an end use. In some cases, the number of equipment categories may approach the number of buildings, producing misleadingly high fractions of variance explained. Also, if any two explanatory variables (X_{ie}) are highly correlated (a nearly constant ratio of capacity density for computers and office equipment, for example), then it is difficult to accurately determine the relative magnitudes of the utilization factors. This may lead to an unrealistically high utilization factor for one and a correspondingly low estimate for the other. Similarly, when one of the variables is strongly negatively correlated with the loads across buildings, a negative utilization factor may result, even though it is unlikely that the equipment generates electricity!

These statistical problems are managed by (1) combining equipment categories when the capacities of two categories are highly correlated; (2) further reducing the number of equipment categories as required to achieve a workable ratio of the number of observations to number of explanatory variables; (3) using a standard statistical procedure known as stepwise regression that iteratively selects variables in decreasing order of variance explained (generally only one of two highly correlated variables is retained); and (4) equipment categories for which negative (and therefore impossible) coefficients result are dropped as candidates, and the stepwise procedure repeated until all resulting coefficients are positive.

To reduce inflation of the selected coefficients to reflect loads from equipment categories rejected by the stepwise procedure, very loose selection criteria were employed: the significance level (α-statistic) for entry and retention in the stepwise model was set at 0.90. The fraction of variance explained (R^2) by the resulting regressions varied widely; most were greater than 0.6 and many were above 0.9. One or more utilization factor estimates were obtained for about 80% of the combinations of equipment categories and building types, with multiple estimates available for most of these.

Where multiple estimates for an equipment category occurred, they were often very similar, particularly those with high statistical significance. However, differences may legitimately occur if there is a systematic bias in the type or usage of the equipment with respect to the end use on which it is metered. For example, computers metered on the Data Processing end use are much more likely to be large mainframe computers, while personal computers are typically metered on the Receptacles end use. (As shown below, this bias can be used to advantage in estimating separate utilization factors for personal and large computer equipment.) Where this is not the case, one utilization estimate may be more valid than another because it represents the majority of the equipment in the category, or because it is derived from a regression which is dominated by the capacity density for the equipment category of interest.

In recognition of the uncertainties involved in the regression process, two additional steps were taken. First, because of possible bias in the nature or usage of the equipment metered on specific end uses, the metered loads were combined in ways that ensured that all or nearly all devices in an equipment category were included. In the example of the computer equipment, by combining the Data Processing, Receptacles, and Mixed General end uses into a single regression, all the computer equipment is represented and the combination contains a properly weighted average of both types. (One such combination regressed the capacities of *all* the equipment categories against the sum of the end-use loads involved.) These additional regressions provide supplementary estimates as well as a means of cross-checking for bias.

The second response to the uncertainties in the regression process was the development of a heuristic approach to recommending specific utilization factors for each building type. This selection process formally structures the cross-checking of the estimates and allows systematic application of the qualitative judgments suggested above. The first three steps of the selection process focus on ranking the end-use regressions by their explanatory power. In Step 1, the regressions were ordered by fraction of variance explained (R^2). In Step 2, any regressions in which the degrees of freedom were overly constrained (the ratio of equipment categories to buildings is high) were dropped from consideration. In Step 3, any regressions resulting in unreasonably large coefficients were also dropped from consideration, if the categories involved also had large capacity densities (inordinately large energy consumption was attributed to them, reducing all the other utilization factors accordingly).

In the final steps, the selection process focuses on each equipment category, in turn. In Step 4, the ordering of the regressions was used to select a "trial" utilization factor from among those with the highest level of statistical significance (three levels were defined by $\alpha \leq 0.1$, $0.1 < \alpha \leq 0.9$, and $0.9 < \alpha$). In Step 5, if the capacity of the equipment in the category is more "purely" metered on another end use that produced a utilization factor of equally high significance, the trial factor was replaced. Finally, in Step 6, if bias in the type or usage of the equipment with respect to the end use on which it is metered was likely, the trial factor was removed from further consideration and Steps 4 and 5 repeated to select a new trial factor from another regression.

Because of a particular emphasis on computer equipment, the bias in the types of computers metered on the Data Processing end use and the Receptacles plus Mixed General combination (20% and 1% of the capacity density consisting of large computers, respectively) was used to estimate separate utilization factors for large and personal computer equipment in offices. The separate utilization estimates obtained for computers from the two regressions (20.0% and 35.8%, respectively) were used with the relative proportions of the equipment capacities to algebraically solve a system of two equations and two unknowns, producing separate utilization estimates for each category.

Recommended Utilization Factors

The resulting utilization factors are shown in Table 3. Nearly complete sets of utilization factors were determined for the food preparation and

Table 3. Recommended Equipment Utilization Factors (%)

Equipment Category	All Bldgs.	Office	Retail	Restaurant	Grocery	Warehouse	Grade School	Other	University	Hotel/ Motel
Office (General)	**22.6**	**14.4**	**18.6**	**19.1**	**44.9**	**32.9**	o	21.9	o	o
Computer	**33.9**	**20.0**	**58.0**	12.1	**44.6**	**8.3**	o	w	o	g
Personal Computer		19.2@								
Large Computer		99.9@								
Task Lighting	13.3?	14.2?	37.1	21.8?	r	12.6?	25.8?	w	s	o
Laboratory		1.9?-	o	o	o	o	o	o	o	o
Vertical Transport.		**1.5**	o	o	o	o	o	o	o	o
Shop		4.3?	2.1	r	58.1?-	0.7?	o	0.0?	o	o
Miscellaneous		**10.0**	w	**61.8**	**92.8**	0.9?	12.2?	w	s	w
Material Handling	5.9?	1.5	o	43.8	7.8?	13.2?	o	0.3?-	o	o
Food Preparation	8.5	1.5	R	9.1	15.1	5.4?	1.0?	1.0	s	o
Refrigeration	**27.0**	12.9	**30.1**	**18.7**	**40.3**	**78.4**	**25.9**	**54.3**	s	o
Sanitation		R	R	**1.7**	6.5?	R	R	R	R	R
Hot Water	5.7	4.3	1.2	**13.8**	15.1?	0.5?	19.3	5.0?	s	o
# of Bldgs =	65	14	12	7	10	11	4	4	0	0

Notes indicating source of recommended utilization factor when filled table is required:
o = filled with Office r = filled with Retail R = filled with Restaurant
w = filled with Warehouse s = filled with School g = filled with Grocery

Statistical significance is indicated for each utilization factor by:
bold = high ($\alpha \leq .05$) normal = moderate ($0.05 < \alpha \leq 0.1$) ? = low ($0.1 < \alpha$)

Additional notes on utilization factors: - = based on 1 building @ = algebraic estimate

See text for other issues regarding application of the results.

refrigeration equipment across building types, and for the office, grocery, restaurant, and warehouse building types for most of the equipment categories. These building types also tend to have the most utilization factors with high levels of statistical significance, so the utilization factors from them can be used with more confidence than those from the other building types. The statistical significance of each utilization factor is indicated in Table 3. Those indicated in bold print should be very reliable; those indicated with question marks should be used only with caution.

Note that the sample sizes are smaller than those in the capacity density summary (Table 2), because buildings could not be used if metered data were not available or if the equipment load inventory did not trace individual devices to specific end-uses on the metering equipment. (This occurs for a few sites installed prior to establishing this aspect of the protocol for the equipment inventory.) Most of metered data used in the regressions is from the calendar years 1987 and 1988. The other limitations discussed in a previous section, Notes Regarding Application of the Results, also apply here.

The utilization results are illustrated here by example. It is reassuring to note that the mainframe computers in offices appear to be in continuous operation, while personal computer equipment utilization is about 19%. This is also reasonable, based on eight business hours per day, five days per week, and a load factor of 50% (8/24 * 5/7 * 50% = 12%). This suggests that a significant number of the personal computers are probably left on overnight. The utilizations of office and task lighting equipment (both 14%) are similar but slightly less. Utilizations of elevators (vertical transportation-intermittent), laboratory, materials handling, and food preparation equipment in offices are very low (less than 2%). Hot water equipment utilization is also low at 4%.

Higher utilization factors for computer equipment in retail stores (58%) and groceries 45% are consistent with their use of computerized cash register and inventory control systems that typically remain on all the time and probably have load factors that resemble those of personal computers (~50%). Lower factors for restaurants (12%) and warehouses (8%) are consistent with use of personal computer systems for office-like functions on a part-time basis.

No utilization factor estimates are directly indicated for the hotel/motel buildings or university buildings, as sample size for these building types is too small. For many purposes, however, some estimate of the utilization of all the categories of equipment in a building type is better than none at all. To support this need, the recommended utilization factors may be extrapolated to all equipment categories in all building types. This extrapolation is based on postulating that utilization is probably a function of the activities conducted in the buildings, i.e., the "office" function in a warehouse is probably much like an office building. Suggested values, used later to develop regional load estimates, are indicated in Table 3. Clearly, extrapolated utilization factors are subject to large uncertainty.

Testing of the Utilization Factors

The derived utilization factors were tested by predicting end-use energy consumption (using the equipment capacity densities) for each of the buildings used in the development of the utilization factors. This comparison is a rough check on the methodology when multiple estimates were available, when the selected utilization factor was drawn from a regression that incorporated only part of the capacity for the equipment category, or when it was extrapolated from another building type. While not a rigorous statistical test, it serves as a consistency check for some of the judgments that were used in selecting from multiple estimates. The predicted and actual loads were then averaged across buildings.

The agreement between actual and predicted total equipment loads was very good for office, retail, grocery, and restaurant buildings; the overall discrepancies were -3%, 4%, -2%, and 3%, respectively. The average error for warehouses was larger at 13%. The discrepancy between actual and predicted loads for the grade school and other building types was larger, because the sample sizes are smaller and most of the utilization factors were extrapolated. In general, at the end-use level, the loads were also in fairly close agreement.

CONSUMPTION ESTIMATES BY EQUIPMENT CATEGORY

The primary unit of commercial sector energy consumption is the energy use intensity (EUI, kWh/ft^2), the energy consumption per unit floor area. The EUI for an equipment category can be estimated, by rearranging Equation (3), as the product of the capacity density, the number of hours in a year, and the utilization factor. The utilization factors extrapolated to all building types (Table 3) were used to estimate EUIs for each of the equipment categories. The results are shown in Table 4. Again, the limitations discussed previously in Notes Regarding Application of the Results apply here.

For example, large computers have the highest consumption of any equipment category in large offices at nearly 2.0 $kWh/ft^2 \cdot yr$, while personal computer equipment consumes nearly 1.1 $kWh/ft^2 \cdot yr$. This is followed by general office equipment at over 0.8 $kWh/ft^2 \cdot yr$. Despite its high capacity density, hot water equipment consumes less than 0.1 $kWh/ft^2 \cdot yr$ due to its low utilization. In small offices, large computer equipment also has the highest estimated consumption at 1.6 $KWh/ft^2 \cdot yr$, followed by office equipment at 0.9 $kWh/ft^2 \cdot yr$ and personal computers at 0.5 $kWh/ft^2 \cdot yr$.

In large retails, task lighting has by far the highest estimated load (1.0 $kWh/ft^2 \cdot yr$), primarily for display purposes. Office and personal computer equipment consume far more per square foot in small retail than in large retail buildings, as the required

Table 4. Estimated Commercial Building Electrical Equipment Loads (1987/88) EUI Estimates By Building Type and Total Pacific Northwest Regional Loads

Equipment Category	Electrical EUI Estimates (kWh/ft^2-yr)											Estimated Regional Total Load (MWa)
	Small Office	Large Office	Small Retail	Large Retail	Res-taurant	Grocery	Ware-house	Grade School	Univer-sity	Other	Hotel/ Motel	
Office (General)	0.93	0.84	0.85	0.06	0.26	0.29	0.63	0.10	0.74	0.16	0.04	77.32
Personal Computer	0.46	1.07	0.60	0.02	0.09	0.13	0.07	0.01	0.55	0.00	0.03	49.47
Large Computer	1.58	1.98	0.03	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	63.47
Task Lighting	0.12	0.06	0.01	1.01	0.14	0.14	0.01	0.01	0.00	0.00	1.60	34.18
Laboratory	0.02	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	5.70
Vert.Trans-Contin.	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Vert.Trans-Intrmt.	0.03	0.14	0.00	0.03	0.02	0.01	0.01	0.00	0.02	0.00	0.00	4.03
Shop	0.05	0.05	0.22	0.32	0.00	0.92	0.08	0.02	0.26	0.02	0.01	20.71
Misc.-Continuous	0.05	0.11	0.00	0.00	0.96	0.38	0.00	0.00	0.04	0.00	0.00	13.67
Misc.-Intermittent	0.15	0.68	0.07	0.01	0.82	1.14	0.00	0.44	0.67	0.05	0.15	51.55
Material Handling	0.02	0.02	0.04	0.02	1.04	0.22	0.39	0.00	0.06	0.09	0.01	20.87
Food Prep.-Contin.	0.27	0.08	0.45	0.19	7.66	3.19	0.14	0.10	0.06	0.08	0.28	110.65
Food Prep.-Intrmt.	0.02	0.01	0.10	0.01	1.50	0.85	0.01	0.01	0.00	0.01	0.04	21.56
Refrig.-Unitary	0.42	0.22	1.19	0.11	3.98	7.09	0.46	0.28	0.23	0.71	0.35	161.58
Refrig.-Central	0.05	0.06	0.33	0.05	5.83	25.56	0.00	0.10	0.00	0.00	0.01	220.40
Sanitation	0.03	0.04	0.01	0.01	0.09	0.04	0.01	0.03	0.00	0.77	0.16	36.90
Hot Water	0.36	0.10	0.21	0.03	3.10	1.44	0.04	5.54	1.24	0.37	1.18	214.08
Floor Area (10^6 ft^2) =	129.2	174.5	186.6	98.0	71.1	55.3	108.6	201.0	85.2	359.4	95.1	

office functions are similar but not proportional to floor area. In restaurants, food processing and refrigeration equipment show high estimated loads (9.2 and 9.8 kWh/ft^2·yr, respectively). In groceries, the refrigeration loads exceed those of all other equipment categories (25.6 and 7.1 kWh/ft^2·yr for central and unitary refrigeration equipment, respectively), although the food preparation estimate is also high.

The cumulative conservation potential for an equipment category is, in part, indicated by the total regional loads it produces. Regional equipment category loads were estimated by multiplying the estimated equipment EUIs by the total floor area in the region for each business type. Estimated total floor areas for each building type in the Pacific Northwest region are shown in Table 4. These floor areas are abstracted from the Pacific Northwest Nonresidential Energy Survey (PNNonRES) (Bonneville Power Administration and ADM Associates, Inc. 1989). The results, displayed in average megawatts (MWa), are included in Table 4. The three equipment categories with the largest contribution to the estimated regional loads are central refrigeration (220 MWa), service hot water (210 MWa), and unitary refrigeration (160 MWa). Computer loads (personal and large combined) comprise over 110 MWa.

DISCUSSION

The results of this analysis help close the knowledge gap about what constitutes commercial equipment loads. As presented in this paper, the results are designed to inform other analysts of commercial sector loads and conservation resource potential. While the usefulness of these results are likely obvious to many readers, key applications for each of the three properties developed (capacity densities, utilization factors, and consumption estimates) are used in this section to selectively illustrate the significance of the findings.

The capacity density (and soon to be published device density) results provide an unprecedented view of the composition of the equipment inventory in commercial buildings in 1985/86. Programs designed to impact a given type of equipment can target market segments that will have the largest impact, and use delivery mechanisms appropriate to the building type and the nature of the equipment involved. Until the PNNonRES data become available, this is the best such planning information available.

The utilization factors also have direct relevance to the design of conservation programs and technologies. For example, the low utilization of hot water equipment in much of the commercial sector suggests oversizing of tanks; hence standby heat losses might be reduced by decreasing tank sizes or using demand water heaters. Similarly, devices to turn off large computer systems appear inappropriate, since they are clearly left on most of the time. Technologies that save energy during operation may be more appropriate. On the other hand, personal computer equipment is frequently turned off, and so programs built around devices that turn them off when not in use might be very effective. If load factors are developed from manufacturers' data or other sources (some are provided for computer equipment by Norford, et al. 1988), these can be divided into the utilization factors developed here to produce time of use estimates. This is a valuable topic for future research.

The capacity density and utilization estimates produced provide default assumptions or "reality checks" for energy audits. Since loads not attributed to equipment are incorrectly assigned to other end uses by the audit process of matching overall fuel bills, this information has the potential to substantially improve the accuracy of the energy audit savings predictions for all end uses. The utilization factors can also be used to disaggregate equipment loads from end uses when they are not separately metered. For example, in some of the ELCAP buildings, a portion of the lighting and equipment loads is metered together (and assigned to the Mixed General end use) for reasons of cost efficiency. The results of the analysis reported here have been used to estimate the individual contributions for lights and equipment in these buildings (Taylor and Pratt 1989).

The process of estimating loads by equipment type can be used to project future consumption resulting from changes in equipment population or usage, such as increasing capacity densities of personal computer equipment or the effect of networks causing them to be left on at night (given assumed or measured load factors). The PNNonRES is currently collecting survey data for a larger, statistical sample of regional commercial buildings, and when it becomes available it can be used with the equipment utilization factors developed here to improve the regional load estimates.

By multiplying the consumption estimates by the estimated floor area in the region for each building type, an estimate of overall consumption by each category of equipment is provided. This view is valuable for quantifying the potential impacts of technologies or programs that might be developed for an equipment type across various types of buildings. The total commercial sector miscellaneous equipment load in the Pacific Northwest is estimated to be over 1100 megawatts, or about one third of the total commercial load. This represents over two coal-fired power plants. The magnitude of this estimated load indicates considerable conservation potential in equipment loads, in aggregate. The challenge is to design technologies and programs to effectively reduce consumption in this widely diverse set of devices and usage patterns.

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